The mean value we have found for the susceptibility of liquid oxygen is 324×10^{-6}, and many of our values for it are exactly 314×10^{-6}.

It seems therefore possible that for paramagnetic bodies over wide limits of density and temperature we may find that the magnetic susceptibility varies directly as the density and inversely as the absolute temperature.

We desire to add that our thanks are due to Mr. J. E. Petavel and Mr. J. T. Morris, for their assistance in carefully carrying out the tedious work of the ballistic observations, necessary to determine the field of the electro-magnet we have used.

"Aluminium as an Electrode in Cells for Direct and Alternate Currents." By E. Wilson. Communicated by Dr. J. Hopkinson, F.R.S. Received May 11,—Read May 26, 1898.

This paper deals with the apparent great resistance which aluminium offers to the passage of an electric current when used as an anode in cells containing, for instance, such an electrolyte as alum in water. The following are references to papers which deal in whole or in part with this or other properties of aluminium when employed as an electrode in electric cells.

Wheatstone. 'Roy. Soc. Proc.' Read April 26, 1855. This is the earliest paper I have found dealing with the metal aluminium in voltaic cells, but Wheatstone does not appear to have noticed the apparent great resistance mentioned above.

Heeren. 'Mittheil. des Gewerbevereins für Hannover,' Jahrg. 1855, p. 342. Reference is made in this paper to Wheatstone's experiments.

Buff. 'Liebig's Annalen,' 1857, vol. 102, p. 269. The author of this paper points out that nine Bunsen elements were not able to pass a current through a cell having aluminium as an electrode. This is the first mention of this property I can find.

Ducretet. 'Comptes Rendus,' 1875, vol. 80, p. 280; also 'Journ. de Phys.,' 1875, vol. 4, p. 84. Observed great resistance in dilute sulphuric acid due to aluminium plate.

Beetz. 'Wied. Ann.,' 1877, vol. 2, p. 94. Supposes oxygen to be the cause of this apparent high resistance.

Winkelmann. 'Wied Ann.,' 1883, vol. 20, p. 91.

Wright and *C. Thompson.* 'Phil. Mag.,' 1885, Part 9, Series 5, vol. 19, pp. 27, 116, 203. Call attention to the non-compliance of aluminium with thermochemical data. Reference is made to the work of Julius Thomsen.

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Laurie. 'Phil. Mag.,' 1886, Series 5, vol. 22, p. 213.   Investigates the effect of amalgamating aluminium, and points out the important part played by the oxide or suboxide of aluminium.

Streintz. 'Wied. Ann.,' 1887, vol. 32, p. 116; also *ibid.*, 1888, vol. 34, p. 751.   Suggests a kind of dielectric polarisation distinct from ordinary electrolytic polarisation as cause of the apparent high resistance of aluminium.

Herroun. 'Phil. Mag.,' March, 1889.   Refers to the disconformity of aluminium in voltaic cells with ordinary theory.

Hutin and Leblanc. 'Étude sur les Courants Alternatifs et leurs Applications Industrielles,' Part 2, Chap. 10, p. 135.

Graetz. 'Wied. Ann.,' 1897, vol. 62, No. 10, pp. 323—327 ; also 'Journ de Phys.,' 1898, Series 13, vol. 7.   This paper specially deals with alternate currents and will be referred to again.   With regard to direct currents, Graetz gives 22 volts as the electromotive force which aluminium as anode is able to oppose.

Pollak. 'Comptes Rendus,' 1897, vol. 124, p. 1443.   With alkaline solutions, Pollak says he can overcome 140 volts continuous pressure.   Proposes to use aluminium as one pole of a cell for the purpose of producing a uni-directional current from alternate currents.

Lang. 'Wied. Ann.,' 1897, vol. 63, pp. 191—194.   Uses an electric arc with aluminium and carbon poles for the purpose of rectifying an alternate current.

PART I.

Direct Currents.

Two sizes of cells have been used in these experiments, each having aluminium and carbon electrodes.   The large size consists of one aluminium plate, $\frac{1}{16}$ inch thick, and one carbon plate, $\frac{1}{4}$ inch thick, separated by ebonite bolts and nuts, the distance between the plates being $\frac{1}{4}$ inch.   The surfaces thus opposed to one another in an electrolyte of saturated potash alum in water have each an area of 36 square inches.   The aluminium plate was not bought as being specially pure, and may have 2 per cent. impurities.   After making preliminary experiments with alternate and direct currents over a lapse of four days, the following experiment was made with this cell and was repeated.

An exploring electrode was inserted midway between the plates, and consisted of a platinum wire sealed into a glass tube.   The wire beyond the tube had a length of about 2 inches, and was coiled into a small spiral, the plane of the spiral being parallel with the surfaces of the plates.   A Kelvin quadrant electrometer was arranged with a two-way switch, so that the potential between this electrode and

either the carbon or aluminium plate could be observed. The cell was placed in series circuit with another, similar in all respects, except that the distance between the plates was $\frac{1}{8}$ inch instead of $\frac{1}{4}$ inch, an adjustable resistance, and an ammeter. By means of a reversing switch this circuit could be reversed across the poles of twenty-two storage cells having a potential difference of 44 volts. The temperature of the cell was about 12° C. The negative pole of the storage cells was connected to the aluminium plate and the current adjusted to 3·6 amperes, the potential difference between the aluminium and carbon plates being 4·4 volts, and gas evolved freely. On reversing the connections, that is, placing the positive pole of the charging battery to the aluminium plate, the current, so far as this ammeter could show, was zero, the potential between carbon and aluminium being about 22 volts. The surface of the fluid was maintained in a state of agitation, but no gas was evolved, except in very small quantity, if any.

The figures in Table I show how the potentials between the

Table I.

Time in minutes after reversal.	Reversal from Al anode to Al cathode.			Reversal from Al cathode to Al anode.		
	Volts between Al plate and exploring electrode.	Volts between C plate and exploring electrode.	Amperes.	Volts between Al plate and exploring electrode.	Volts between C plate and exploring electrode.	Amperes.
0	+16·6	+1·63	0	−1·74	−2·73	−3·56
About $\frac{1}{2}$	−3·81	−2·04	−3·35	+14·3	+0·30	+1·20
1	−2·48	−2·40	−3·42	+18·2	+1·57	+0·64
2	−2 23	−2·79	−3·47	+19·1	+1·64	0
3	−1·9	−2·84	−3·49	+19·6	+1·67	0
4	−1·9	−2·84	−3·50	+20·0	+1·68	0
5	..	..	..	+20·5	+1·67	0
7	−1·65	−2·84	−3·55			
13	−1·74	−2·73	−3·56			
190	..	..	..	+17·9	+1·76	0

exploring electrode and the carbon and aluminium plates respectively, as also the current, varied in terms of time after reversal took place. The time between the two reversals in Table I was 27 minutes. There is no doubt but that·the current, when reversal took place from 3·6 amperes, first crossed the zero and acquired an opposite sign, finally coming to zero of the instrument.

This is an important point, and was fully established during

another set of experiments undertaken to find the resistance of the electrolyte. For this purpose the plates were separated to the extent of $1\frac{3}{16}$ inch, and two platinum exploring electrodes used, the distance between them in the electrolyte being $\frac{15}{16}$ inch, along a straight line perpendicular to the parallel surfaces of the plates. Each time reversal took place from negative to aluminium, to positive to aluminium, the potential between these electrodes changed sign, and gradually returned to near zero. The results of the experiments on resistance show that at this temperature the resistance of a layer of electrolyte of area equal to the area of the plate submerged, and of length equal to the distance between the electrode and the plate, that is $\frac{1}{8}$ inch in the experiment of Table I, is 0·063 ohm. The correction is therefore small with current 3·6 amperes, and is negligible when the positive pole is connected to the aluminium.

The next set of experiments were carried out with aluminium $\frac{1}{16}$ inch thick, of 99·5 per cent. purity, the electrolytes being specially pure, and only distilled water used. The cells used are of a smaller size, and each consists of one aluminium plate, $1\frac{1}{2}$ inches wide, having a carbon plate on each side of it, the distance between the aluminium and carbon being $\frac{5}{32}$ inch, the carbon plates being $2\frac{1}{2}$ inches wide and $\frac{1}{4}$ inch thick. The aluminium plate was submerged $2\frac{3}{4}$ inches in the electrolyte, so that the total area for current is $8\frac{1}{4}$ square inches.

Two such cells were prepared, one with a 10 per cent. by volume solution of H_2SO_4 in water, the other with a saturated solution of potash alum, and left for forty-seven hours with a current of $\frac{1}{24}$ ampere passing through each in series, the positive of charging cells being connected to aluminium. At the end of this time, and with this current, the potentials across the cells were 2·4 volts for the H_2SO_4 solution, and 9 volts for the alum solution. On breaking the circuit, the potential of the H_2SO_4 solution cell fell to about 0·38 volt in one minute, and rose fairly gradually to 2·4 volts on making circuit. The alum solution cell lost its potential immediately on breaking circuit, that is, the electrometer needle appeared to return to zero, as though there were no opposing electromotive force. When the current was reversed, that is negative to aluminium, and still of the value $\frac{1}{24}$ ampere, the H_2SO_4 solution cell gave 0·24, and the alum solution 1·29 volts.

The aluminium plate which was formed in the H_2SO_4 solution, together with its carbon plates, were next washed in distilled water, and placed in a saturated solution of alum. Eleven storage cells were connected without extra resistance in circuit to each of these cells positive to aluminium, and the resulting current noted. The plate which had been formed in H_2SO_4 allowed about 0·2 ampere to pass, and in 4 hours 10 minutes this current had risen to about

1 ampere, the temperature of the cell having risen. The plate formed in alum solution only allowed 0·083 ampere to pass. The two cells were then placed in series and left for 13 hours, with $\frac{1}{24}$ ampere passing from the aluminium to carbon plates in each.

The following test was then made. The cells had opposed to them, aluminium to positive, in turn from 1 to 20 storage cells, without extra resistance, rising a cell at each step, the resulting current and potential across the terminals being noted. The results are given in Table II. We see that from 1 to 18 storage cells the

Table II.

Number of storage cells applied.	Plate formed in dilute H_2SO_4.			Plate formed in alum solution.		
	Volts across cell.	Amperes.	Tempera-ture C.	Volts across cell.	Amperes.	Tempera-rure C.
1	1·89	0·0005	13	1·89	0·0009	13
2	3·78	0·026	..	3·87	0·026	
3	5·67	0·034	..	5·76	0·036	
4	7·65	0·036	..	7·56	0·053	
5	9·54	0·036	..	9·45	0·053	
6	11·3	0·050	..	11·3	0·077	
7	12·6	0·055	..	12·6	0·062	14
8	14·4	0·062	..	14·4	0·098	
9	17·1	0·069	..	16·2	0·108	14·5
10	19·8	0·070	..	19·8	0·12	15·5
11	21·6	0·079	..	21·6	0·13	15·7
12	23·4	0·089	..	23·4	0·144	16
13	25·2	0·096	..	25·2	0·161	17
14	27·9	0·120	..	27·9	0·178	
15	29·2	0·127	20	29·2	0·20	18
16	31·5	0·191	..	31·5	0·191	
18	34·2	0·987	..	35·1	0·34	
20	39·1	increased rapidly to 4 amperes, circuit then broken	21½	39·6	increased rapidly to 1 ampere, circuit then broken	19½
16	29·7	0·9	23	30·6	0·29	

currents gradually increase in each, the plate formed in H_2SO_4 having an apparent greater resistance, up to about 16 cells. With 20 cells applied the H_2SO_4-formed plate gave way with great rapidity, and in a very short time, about fifteen seconds, the current was 4 amperes, the temperature of the cell rising also from 21° C. to 23° C. The alum-formed plate seemed more stable with 20 cells, but speedily allowed a current of over 1 ampere to pass. On going back to 16 cells the currents were 0·9 ampere in the H_2SO_4-formed plate, and 0·29 ampere in the alum-formed plate.

This brings us to the effect of temperature upon potential for a given current. The cell containing the aluminium plate formed in alum solution above referred to was placed in an oil bath, the temperature of which could be varied. The current was that due to 56 storage cells, through a considerable external resistance, about 650 ohms during heating, and 2280 during cooling. There was an excess of alum in the cell, and the solution was kept saturated. The variation of potential between the aluminium and carbon electrodes was noted, as also the temperature of the cell. The results are given in Table III.

Table III.

Time.		Amperes.	Volts.	Temperature C.	Remarks.
h.	m.				Current switched on
0	0	0·16	rising	13·5	+ to Al
0	5	0·124	29	,,	,,
0	10	,,	30	,,	,,
0	15	0·169	1·3	14	— to Al
0	16	0·122	32	,,	+ to Al
1	55	0·132	26·1	20·4	,,
2	0	0·172	1·1	,,	— to Al
	1	0·124	31	,,	+ to Al
	8	0·132	24·7	25	,,
	12	0·139	20·2	29·5	,,
	20	,,	11·7	36·5	,,
	22	0·141	7·65	43	,,
	27	0·143	7·2	52	,,
	28	0·155	1·1	,,	— to Al
	30	0·141	7·2	56	+ to Al
	33	0·143	5·4	61	,,
	37	0·148	3·0	70	,,
	44	0·0518	0·18	72	,,
3	15	,,	0·72	63	,,
	25	,,	1·3	56·5	,,
	31	0·0509	2·3	51	,,
	50	,,	2·7	40	,,
22	50	0·048	10·3	12	,,

We see that as the temperature of this cell rises from 13·5 to 70° C., the potential difference falls from 30 to 3 volts. The experiments already made on the resistance of the electrolyte will only account for 0·043 volt at 13·5° C., and 0·025 volt at 57° C. with the currents 0·124 and 0·141 ampere as given in Table III. The conclusion is that temperature has an effect upon the apparent high resistance of an aluminium plate and its film, the subject of this paper. This points to the fact, that in practice for high apparent resistance, it would be necessary to cool or circulate the electrolyte with such dissipation of energy, that the cell would otherwise acquire a high temperature.

In Table III we see that as the cell cools with a smaller current of about 0·051 ampere, the potential between the aluminium and carbon plates rises. In this case at 56, and 12° C., the electrolyte would account for 0·0093 and 0·017 volt respectively.

It was thought that if a plate of aluminium with its film were submerged in mercury, the resistance between the metal and mercury might give an idea as to whether resistance, pure and simple, played an important part in the effects observed. The plate originally formed in H_2SO_4 solution was carefully removed, washed in distilled water and dried, and half submerged in clean mercury. Storage cells ranging in number from 1 to 15 were applied as in Table II, but in each case the poles were also reversed so as to test the insulation with the two directions of currents. The results show that this film on aluminium is a fairly high insulator, but it was not stable. At times the resistance was zero, when a sharp noise occurred in the cell like sparking between points in air, and the insulation was immediately restored. With 16 volts applied, the apparent resistance was about 10,000 ohms, whereas from Table II we see the apparent resistance of the whole cell is 230 ohms at 14 volts, the positive pole being connected to aluminium. I should say, judging from the number of times the film broke down, that it was more stable when the positive pole of the charging battery was connected to the aluminium; but in either direction the resistance, when established, had the same order of magnitude. Up to six cells, no extra resistance was included in the circuit as the film was stable, after this a resistance was inserted so as to keep down the current when the film broke down, as then the potential between Al and Hg was zero. Even at 30 volts the film was able to restore its insulating properties, but very rarely. On removing the plate, a film was left on the mercury where it had been in contact with the film on the aluminium plate.

Another set of experiments was made with two cells having as electrolytes a 5 per cent. solution of H_2SO_4 in water, and a saturated solution of potash alum in water. The area of the pure aluminium plate exposed to the fluid was 17 square inches in each cell. A current of 1 ampere was passed for four hours through the H_2SO_4 solution cell, and three hours through the other. At the end of these times the temperatures were respectively 33 and 51° C. With the 1 ampere passing from Al to C, the potentials between the plates were respectively 6·3 and 20 volts. The cell containing the plate formed in potash alum solution was then heated, the current through it being kept fairly constant by means of a considerable external resistance and 110 volts. It was then cooled by placing it in a freezing mixture of ether and carbonic acid snow. The temperature in this case was reduced somewhat rapidly, and a portion of the electrolyte at the bottom was frozen, probably a cryohydrate, leaving liquid above.

The temperature of this liquid portion did not fall below zero centigrade. The results are given in Table IIIA. When comparing these

Table IIIA.

Time.	Amperes.	Volts across one cell.	Temperature.	Remarks.
			Heating.	
			° C.	
12.45 p.m.	0·154	28·8	17	Al connected to positive pole of
1.0 ,,	0·154	27·0	18	charging cells.
3.40 ,,	0·174	15·3	24	
4.20 ,,	0·170	16·2	25	
6.40 ,,	0·187	16·6	26·5	
			Cooling.	
11.0 a.m.	0·161	29·2	13	The temperatures are those of the
11.3 ,,	0·160	30·1	11	liquid electrolyte.
11.35 ,,	0·158	30·8	3	
12.0 noon.	0·160	31·0	1	
12.30 p.m.	0·168	26·3	2	Bottom portion of electrolyte found
1.0 ,,	0·170	25·2	2	frozen.
1.10 ,,	0·055	4·95	2	
1.12 ,,	0·058	1·35	2	Al to negative.
1.14 ,,	0·235	2·25	2	,, ,,
1.15 ,,	0·165	26·6	2	Al to positive.
2.50 ,,	0 158	31·2	not known	Fluid portion of electrolyte poured away, only frozen portion remaining.

with the results of Table III, one must remember that the areas of the plates in the electrolyte are 17 square inches in Table IIIA and $8\frac{1}{4}$ square inches in Table III. This paper does not deal with the chemistry of the effect discussed. It is known that a clean aluminium plate acquires this film, when simply submerged in alum solution, in the presence of oxygen, without the passage of currents. We have seen that with a given film time is required to develop the effect.

[Note added 19th May, 1898.

The film on these plates has been examined by Mr. Herbert Jackson, of the Chemical Department, King's College, London, and the following is his communication.

         " King's College, London,
            " May 12, 1898.

" Dear Wilson,

" I waited to send you the results of my examination of the aluminium plates until I had looked at them carefully with the

microscope. Not much information, however, is to be gained from
this. The skin over the plates is, however, seen to be full of minute
cracks in every direction, giving the impression of a dried gelatinous
pellicle; not an unexpected appearance if the plate had been covered
when wet with a thin coating of the gelatinous aluminium
hydroxide. The analysis of the film over the metal shows it to
consist of basic aluminium sulphate. The origin of this may of
course have been the formation in the first place of aluminium
hydroxide which subsequently reacted with some of the alum solu-
tion to give the basic compound. How far the formation of this
may have anything to do with electrolysis would, I should think,
be difficult to say without further and more elaborate experiment,
and it must be remembered that a similar coating can be obtained
on an aluminium plate by immersing it in an alum solution and
leaving this freely exposed to the air.

<div align="center">" Yours sincerely,</div>

<div align="right">" HERBERT JACKSON."</div>

I have tried an experiment which I think shows that a film formed
on aluminium by first being placed in contact with an alum solu-
tion and then exposed to the air, gives the same effect as a film
formed in the cell when a current is passed from the aluminium to
a carbon plate through the electrolyte. Two similar bright alu-
minium plates were prepared with carbon plates on either side of
them, the area of aluminium in the electrolyte being $8\frac{1}{4}$ square
inches. The electrolyte consisted of a saturated solution of potash
alum in water. One plate was left in the solution for seven hours
with no current passing, and then exposed to the air for $16\frac{2}{3}$ hours.
The other plate was submerged in the fluid and immediately read-
ings were taken of the current passing and potential difference in
volts between the aluminium and carbon plates. The effect in this
case was exactly what was previously observed. That is to say, the
current being maintained constant at $0\cdot055$ ampere by about 2000 ohms
being inserted in circuit with the cell across about 110 volts,
the potential difference immediately passed from a small negative
value through zero, and after three minutes and forty minutes, had
respectively the values $1\cdot8$ and $2\cdot27$ volts ; the temperatures being
$12\frac{1}{2}$ and $15\frac{1}{2}°$ C. The test was continued. For the next $5\frac{1}{4}$ hours
the current was $0\cdot204$ ampere, it was then dropped to $0\cdot055$ ampere
and kept at this value for $16\frac{1}{3}$ hours. At the end of this time the
potential was 10 volts with $0\cdot055$ ampere, and $28\cdot6$ volts with $0\cdot163$
ampere, the temperature being $15°$ C.

The other plate was submerged in its solution, the potential differ-
ence and current being immediately noted as before. The results in
this case show that the potential, with $0\cdot054$ ampere, rose immediately

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from a small negative value of about 0·2 volt to a positive value of
1·8 volts. After four minutes and forty minutes respectively the
potential with current 0·054 had the values 2·07 and 2·56 volts, the
temperatures being 13 and 15·5° C. This, I think, shows that a film
formed by exposure to the air after being submerged in a saturated
alum solution, has the same effect as another formed in this electrolyte
during the passage of current. This test was continued. After
twenty-four hours, during which the current was 0·0523 ampere, the
potential was 11 volts, with this current passing, and the temperature
16° C.

The two cells were then placed in series and an average current of
0·048 ampere passed through them from the aluminium to carbon
plates for fifty hours. At the end of this time, with current 0 048
ampere, the potentials were 10 in the case of the plate partially
formed without current, and 10·3 in the case of the other; the
temperatures being 19 and 17½° C. respectively. With current 0·121
ampere, the potentials were 26·2 and 27·4 respectively at tempera-
tures 21 and 19½° C.]

Sodium hydrate forming a weak solution in water was tried as an
electrolyte, the area of the Al plate being the same as before, 17 square
inches. The forming current of 0·8 ampere was passed from Al to C
for 2 hours 20 minutes, when the potential between the plates was
13·6 volts, the aluminium plate being covered with a thick black
deposit.

PART II.

Alternate Currents.

The experiments with alternate currents were undertaken in order
to investigate the instantaneous values of potential and current.
One object was to see if the effect we have dealt with in the first
part of this paper has time to properly develop with ordinary
frequencies, and if so under what conditions. Another object was to
see if aluminium is a valuable metal for use in condensers for alter-
nate currents.

Aluminium-Carbon Cells.

If the time taken to develop the effects dealt with in the first part
of this paper were very small compared to the time of a complete
period of an alternating potential applied to the cell, one would
expect to get a practically uni-directional current in the circuit of
the cell under favourable conditions as to temperature and applied
potential. This is not the case with the cells and frequencies dealt
with in this paper. In all these experiments the author has
endeavoured to make the cells the controlling part of the circuit,

that is to say between the terminals of the alternate current machine a small non-inductive resistance and a Siemens dynamometer were the only part of the circuit other than the cells experimented upon. The copper resistance of the circuit including armature was from 1 to 5 ohms.

In the first portion of these experiments, the results of which are given in Table IV, the instantaneous values of the current, and the

Table IV.

Experiment.	Frequency.	First half period.			Second half period.			Ratio of maximum coulombs.	Average watts per period.	Amperes given by Siemens dynamometer.	Average temperature of cell C.
		Maximum volts.	Maximum amperes.	Phase difference 360° = one period.	Maximum volts.	Maximum amperes.	Phase difference 360° = one period.				
(1)	92	8·9	5·2	24°	26	4·0 ·	56°	1·35	26·8	3·28	27
(2)	91	7·8	1·6	57	8·9	1·5	69	1·07	2·65	1·10	9
(3)	91	14·2	16·2	6	33	9·9	42	1·97	120	8·99	26
(4)	74·5	21·1	39·8	3	18·6	26·5	3	1·78	294	21·0	36
(5)	52	13·4	14·5	6	20·2	9·6	24	1·54	86	8·16	35

potential difference between the terminals of the cell, were observed by aid of a Kelvin quadrant electrometer and a revolving contact maker. The cell across which the potentials were observed consisted of one aluminium plate $\frac{1}{16}$ inch thick separated by $\frac{1}{8}$ inch from a carbon plate $\frac{1}{4}$ inch thick, the electrolyte being a saturated solution of potash alum in water. The surfaces thus opposed to one another in this electrolyte have each an area of 36 square inches. Another cell of the same size as the above was placed in series with this cell. Four smaller cells were used in some of the experiments as will be set forth. Each of these consists of a thin aluminium plate opposed to a carbon plate, the opposed surfaces in a saturated solution of alum have each 8 square inches area, the distance between such surfaces being $\frac{3}{4}$ inch.

In Table IV the arrangement of these cells was as follows:— Experiments (1) and (2) all the six cells in series. Experiment (3) the two large cells in series with one another and with the four small cells arranged 2 series 2 parallel. Experiments (4) and (5) only the two large cells in series were used. No attempt was made to cool or circulate the electrolyte, but it had considerable volume and took some time to heat and cool. In all cases there was an excess of salt to insure saturation. Table IV contains the important information obtained from the tests.

These figures show that small currents are accompanied by large

phase difference but the effect we are looking for, namely, a large
ratio between the maximum coulombs in the two halves of a period,
mainly develops with large currents for a given frequency accom-
panied by high temperature and small phase difference.   The average
watts have been deduced from the product of instantaneous volts
and amperes at twenty equal intervals during a period.

The experiments in figs. 1, 2, 3 give results obtained with an
exploring electrode inserted between the plates in the electrolyte as
in the first portion of this paper.   The aluminium and carbon plates
in one of the large cells were separated to $\frac{1}{4}$ inch, and the two cells
kept in series as in experiments (4) and (5) Table IV.   The curves
refer to this cell, and provision was made for obtaining the instan-
taneous values of the current in the cell, and the potentials between
the exploring electrode and either the aluminium or the carbon
plate.

In figs. 1, 2, the Siemens dynamometer in the circuit registered
the same current, namely 3·97 amperes, but the frequencies are 16
and 98·5 respectively.   We see that $\frac{1}{16}$ second is too short to allow
the effect we are looking for to fully develop, since the ratio of the
maximum coulombs is 1·47.   On the other hand, if we examine the
two sets of curves we see that at 98 periods per second the potential
difference between the exploring electrode and aluminium has a
maximum value of 3·63 volts during the half period when the
coulombs have the smaller maximum, whereas at 16 periods per
second, the same maximum current is produced with a larger

Fig. 2. Frequency 98·5

Fig. 3. Frequency 101.
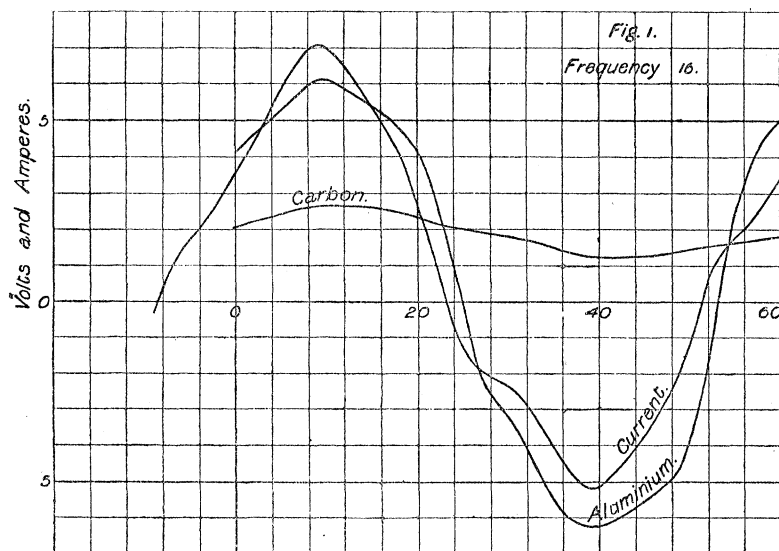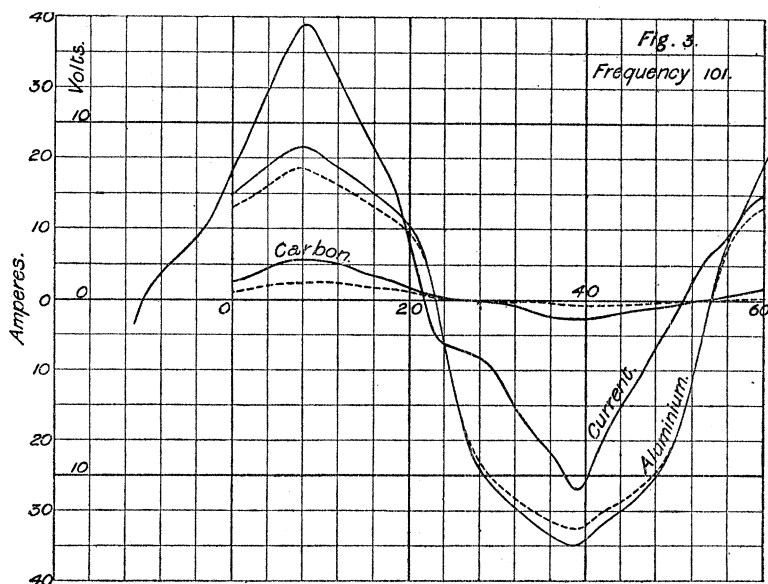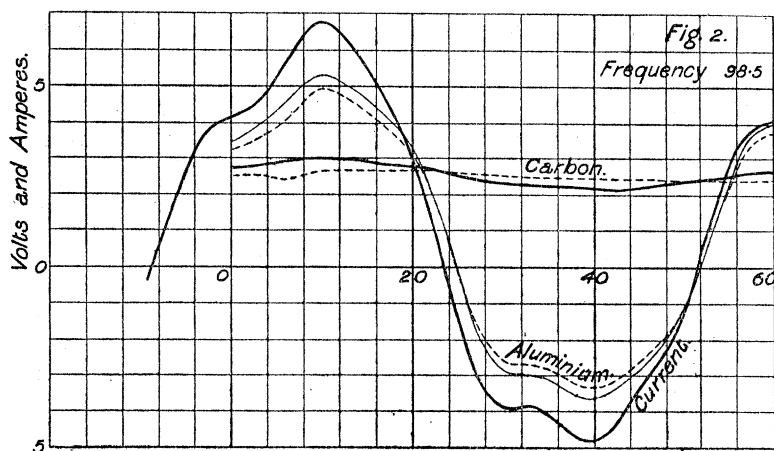
maximum potential, namely, 6·27 volts. That the aluminium plate
was an anode during the half period when the maximum coulombs
were a minimum, was proved by noting the direction of the electro-
meter deflection, when the positive pole of a Clark's cell was con-
nected to the insulated quadrant, and examining the observed
direction of the deflection during the experiment. Experiments
made upon the resistance of the electrolyte with two exploring
electrodes, employing alternate currents, show that at the tempera-

ture at which these experiments were made, namely, $13\frac{1}{2}°$ for the 16 frequency, and $11\frac{1}{2}°$ C. for the 98·5 frequency, the resistance of a layer of the electrolyte of area equal to the area of the plate submerged, and length equal to the distance between the electrode and the plate, has a value of about 0·063 ohm.   The curves of potential in fig. 2 have been corrected for this, and the dotted lines show the results.   The average watts dissipated by electrolytic hysteresis at the carbon and aluminium plates at 98·5 periods per second, fig. 2, are 0·69 and 4·5 respectively.   This takes no account of the resistance of the electrolyte, and has been obtained by taking instantaneous products of potential and current at twenty equal intervals during the period.   During the first half-period work is supplied at the carbon plate on the average at the rate of 4·1 watts ; during the second half-period the plate does work on the system at the average rate of 2·7 watts.   The aluminium plate returns practically nothing to the system.

In fig. 3, the frequency is 101, the ratio of the maximum coulombs in the two halves of the period is 1·7, and the Siemens dynamometer in the circuit registered 20·6 amperes.   The average temperature during this experiment was about 55° C., but had a maximum of 64° C. at the end of the test.   Under these conditions, evaporation of the electrolyte was rapid.   The experiments on the resistance of the electrolyte at this frequency and temperature give 0·033 ohm, and the potential curves have been corrected, the result being shown by the dotted lines.   The average rate of dissipation of energy due to electrolytic hysteresis at the aluminium plate during the period is 153 watts, whereas at the carbon plate this rate is only 9·8 watts. We see that the maximum volts during the half period when the maximum coulombs are a minimum have risen to 13, whereas during the other half period the maximum volts are only $7\frac{1}{2}$.

The paper by Graetz already alluded to, deals with alternate currents ; and two groupings of cells with aluminium plates as the one electrode are given, whereby he proposes to rectify alternate currents. He gives 22 volts as the potential an aluminium cell is capable of opposing, and states that the current could not be measured with a delicate galvanometer.   The first grouping of these cells consists of placing between the poles of the alternator two circuits in parallel, in each of which he places four cells in series. The poles are reversed so that in the one circuit the predominating current will be positive, whereas in the other it will be negative. The other grouping of these cells is shown in fig. 4, and the author states that he gets a unidirectional current in the circuit *xy*.   In this circuit he has operated a direct current motor, and deposited copper.   By superposing one of the current curves in figs. 1, 2, or 3 on the same curve, but with reversed phases, one can form an idea

as to what the resulting current would be in the circuit xy. Curves in fig. 5 were obtained by observing the instantaneous value of the potential difference between the ends of a non-inductive resistance of 0·349 ohm, forming the circuit xy, fig. 4. Four small cells were

FIG. 4.

ALTERNATOR.
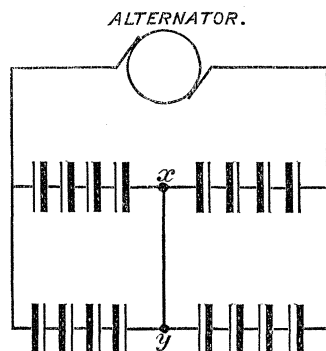
used, each one taking the place of the group of four in the diagram; each or these consists of a thin aluminium sheet and a carbon plate, the opposed surfaces in a saturated alum solution having each 10 square inches, separated by a distance of $\frac{5}{32}$ inch. In fig. 5,

Fig 5.
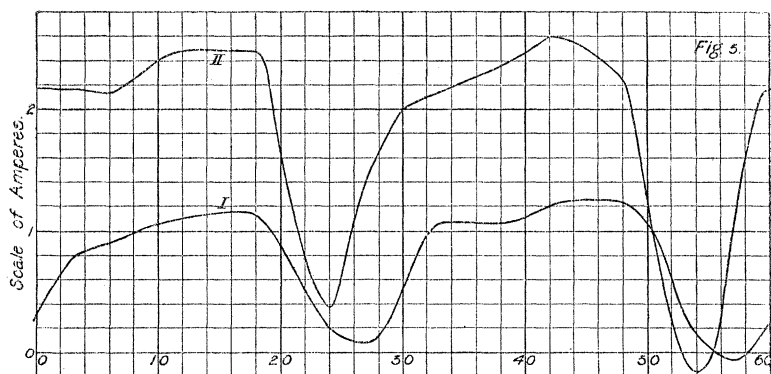
curve I, is the current in xy, when the current from the alternate current machine through the system was 3·96 amperes, as given by a Siemens dynamometer. Curve II is the current in xy, when the Siemens dynamometer read 10·4 amperes. The frequencies were 74 and 73·3, and the temperatures of the cells 25° C. and 44° C. respectively in the two experiments. Graetz states that with cells

of sufficient size 95 to 96 per cent. of the energy of the alternate current can be changed into direct current. The efficiency of such a system as shown in fig. 4 will obviously be the ratio of the rate at which work is done on xy to the rate at which work is done on the whole system by the alternate current machine. If this is to be 95 per cent., then only 5 per cent. must be dissipated in the cells.

An important point in connection with the working of these cells is the wearing away of the aluminium. The thin metal used in the small cells above alluded to is perforated with small holes, but I have not noticed so much deterioration in the thicker sheet. The evaporation of the electrolyte is another matter which needs consideration if the temperature is raised fairly high in working.

Two Aluminium Plates in Alum Solution.

These experiments were undertaken to find what effect as a condenser this metal with its film has with varying frequency temperature and current. The aluminium plates in the two large cells above experimented upon were opposed to one another in a saturated alum solution. The distance between them was $\frac{1}{8}$ inch, and the opposed areas in the solution are 36 square inches on each plate.

The important data have been collected in Table V. As a com-

Table V.

Experi-ment.	Fre-quency.	Max. volts across one cell.	Max. amperes.	Current $\sqrt{mean^2}$, as given by Siemens dynamometer.	Temperature.	Ratio of energy returned to energy supplied per period per cent.	Average phase difference, 360° = one period.	Average rate of dissipation of energy in cell.	Plates.
				Amperes.	° C.			Watts.	
(a)	96	25·0	30	21·6	82	—	12°	—	Al
,,	,,	3·35	,,	,,	24	—	9	—	Fe
(b)	17	46·0	8	3·93	53	0·72	12	150	Al
,,	,,	1·3	,,	,,	11	—	60	---	Fe
(c)	100	52·5	2·6	1·3	14	16·0	54	42	Al
,,	,,	0·25	,,	,,	9	—	—	—	Fe
(d)	92·4	21·0	1·48	—	11	11·2	60	9·24	Al
(e)	92·4	8·0	0·51	—	13½	16·6	57	1·11	Al

parison two plates of ordinary sheet iron of the same area and the same distance apart as in the aluminium cell were placed in a saturated solution of alum and placed in series with the aluminium cell. As before the circuit included a Siemens dynamometer and non-inductive resistance, and potentials were observed for different positions of the phase across the non-inductive resistance, and each cell, by aid of a Kelvin quadrant electrometer and revolving contact maker. On account of the irregular wave form of the curves of potential and

current, the ratio per period of the energy returned to the system by the cell to the energy supplied to the cell, is given as a percentage. If the electrolytic process were perfectly reversible, we should expect the curves of current and potential to have a phase difference of one quarter period, if they were sine curves. An examination of Table V shows that maximum phase difference develops with the smaller currents at lower temperature. In experiment (c) the maximum amperes are 2·5, the maximum volts 53. The curve of potential difference has a maximum rate of change of about 57·5 volts in $\frac{1}{600}$ second, so that an ordinary condenser with maximum current 2·5 amperes would have a capacity of about 72 microfarads. We see, therefore, that aluminium is suited for the plates of condensers. The average watts in Table V have been deduced from the instantaneous product of potential and current at twenty equal intervals during a period.

The foregoing experiments employed saturated potash alum solution as electrolyte. The following experiments deal with soda, ammonia, and potash alums, first when the solutions were saturated, and second when non-saturated. In each of the non-saturated solutions the proportions were thirteen parts of saturated solution at about 12° C. by volume and seventy equal parts of distilled water. Three cells were constructed, each containing two aluminium plates of 99·5 per cent. purity, separated $\frac{1}{8}$ inch apart, and each having 33 square inches of surface in the electrolyte opposed to the other. The results of the experiments are given in Table VI.

With regard to the saturated solutions one may say that at the low frequency 7·5 Table VI the results are not so good as at the high frequency 92·4 Table V. The non-saturated solutions also show a better result with regard to efficiency at the higher frequency.

These plates were not specially formed with direct currents and carbon cathodes before starting the above experiments. In a preliminary experiment of about one hour's duration, before the first series at frequency 33 in Table VI were made, and starting with clean polished plates, the maximum volts for the soda, ammonia, and potash were, a few minutes after starting, 4·4, 21·5, and 32. The maximum current was 0·48 ampere and the phase differences in each case about 70°. The frequency was 23 and the temperature of each cell about 14° C.

An experiment was tried in which two aluminium discs 6 inches diameter and separated $\frac{3}{16}$ inch on an ebonite spindle were submerged to within $\frac{3}{4}$ inch of the centre in a saturated potash alum solution and rotated at 108 revolutions per minute by a small electric motor. In this manner more than half the discs were continuously exposed to the atmosphere. Two brushes bearing on copper discs,

Aluminium as an Electrode in Cells.

Table VI.

Frequency.	Max. volts across one cell.	√Mean² as given by multicellular voltmeter across the three cells.	Max. amperes.	√Mean² as given by Siemens dynamometer.	Temperature of cell in degrees Centigrade.	Ratio per period of energy returned to energy supplied to cell per cent.	Average phase difference, 360° = 1 period.	Average rate of dissipation of energy in cell.	Alum solution in cell.
		Volts.		Amperes.			°	Watts.	
33	16	—	1·73	0·79	15	25·5	78	3·6	Soda, saturated solution.
,,	34	—	2·17	1·03	19	2·5	31	26·2	Ammonia ,,
,,	41	—	,,	,,	19½	2·7	31	25·3	Potash ,,
54·6	37·6	—	1·87	1·12	25½	8·7	44	22·0	Soda.
,,	42·5	—	,,	,,	19	17·3	36	24·0	Ammonia ,,
,,	39·7	—	,,	,,	19	4·3	30	28·0	Potash ,,
7·5	39·7	90	0·525	—	14	7·6	57	9·1	Soda.
,,	48·5	91	0·95	—	15	2·8	48	23·0	Ammonia ,,
,,	42·9	,,	,,	—	15½	1·9	36	21·0	Potash ,,
10·5	21·3	88	0·66	—	13½	3·2	41	5·0	Soda, non-saturated solution.
,,	49·1	92	0·685	—	15½	4·0	48	10·3	Ammonia ,,
,,	44·4	,,	,,	—	16	2·6	36	10·0	Potash ,,
43·2	35·0	89	0·894	—	15	26·0	70	6·0	Soda.
41·3	47·6	,,	,,	—	17	22·0	71	9·6	Ammonia ,,
,,	45·0	,,	,,	—	17½	14·0	65	11·1	Potash ,,
18·5	57·8	120	2·61	1·25	16½	2·0	36	42·4	Soda.
18·1	55·7	117	,,	,,	21	2·1	33	39·4	Ammonia ,,
,,	48·8	,,	,,	,,	20½	1·4	28	37·6	Potash ,,

pressed into good contact with the aluminium discs, served as a means of transmitting current through the electrolyte between the discs. The frequency was 73, the temperature 18° C., and square root of mean square value of current about 1 ampere.   No perceptible difference was observed in phase difference between potential and current when the discs were rotated and at rest in the electrolyte.

The conclusion is that the effect investigated in this paper takes time to develop, and is not fully developed with alternate currents of frequencies sixteen and ninety-eight complete periods per second.   It can be increased by increasing the current density for a given film, and is greatly influenced by temperature.   The metal aluminium with its film is suitable for use as the plates of condensers, if due regard be given to current density and temperature.   It might in some cases be found useful as an equivalent to a metallic resistance.

Messrs. Simpson, Greenbank, and Davy, Student Demonstrators in the Siemens Laboratory, King's College, London, have given me valuable assistance in the experimental part, and in the working out of results.   To these gentlemen I tender my thanks.

" Contributions to the Study of ' Flicker.' "   By T. C. PORTER, Eton College.   Communicated by LORD RAYLEIGH, F.R.S. Received May 13,—Read May 26, 1898.

Much work has already been done on this subject, though little of a quantitative character.   Many observers have described the curious colour sensations which rapid alternations of light and darkness can excite under certain conditions, admirably exemplified in the " spectrum tops."   Foremost amongst those whose experiments and writings have led to the present very general interest in the subjects of flicker, and of the sensation of light and colour, may be mentioned Helmholtz, Silvanus Thompson, Shelford Bidwell, Henry, Charpentier, and Rood; whilst the first to try experiments on the relative sensitiveness of the eye to flicker in light of different colours, seems to have been J. Plateau, who, however, employed pigments, and not the colours of the spectrum.

The writer's first experiments were made to ascertain the exact relative rotations at which the flicker just vanishes in the different colours of the same spectrum, and were carried out (*a*) as suggested by Professor Rood in his ' Modern Chromatics,' with a balanced, blackened, opaque disc, having a broad semicircular arc removed, and (*b*) on a cardboard disc, half black, half white, viewed in the different colours of the spectrum of the second order of a Rowland's plane diffraction grating of 14,434 lines to the inch.   Two sources of light were employed, (*a*) direct sunshine, (*b*) lime-light.   The results